Report for 2005MT47B: Geographic analysis of landuse/land cover change and its relation to nitrogen export in a developing mountain landscape

Publications

- Conference Proceedings:
  - McGlynn, B.L. and K. Gardner. 2006. Landuse change impacts on water quality: The importance of spatial location. Swedish Institute of Hydrology Meeting, Stockholm, Sweden. Invited keynote speaker.
  - McGlynn, B.L., J. Seibert, R. Gresswell, and D. Bateman. 2006. Landscape analysis of stream-upland connections: Implications for runoff generation, biogeochemistry, and in-stream habitat. North American Benthological Society Annual Meeting, Anchorage, Alaska.
  - Gardner, K.K., K. Segal, J.Harder, and L. Shoutis. 2006. Big Sky Institute GK12 Fellows Program: Bringing scientific research into rural classrooms. National Science Foundation (NSF) GK12 Annual Meeting, Washington D.C.
  - Gardner, K., B.L. McGlynn, D. Patten, J. Shanley. 2005. Effects of mountain resort development on streamwater nitrogen export: Importance of spatial location of land use / land cover change. American Geophysical Union Fall Meeting, San Francisco, CA.
  - McGlynn. B.L. and J. Seibert. 2005. Hewlett's legacy: Remaining challenges and possible ways forward. American Geophysical Union Fall Meeting. Fall, 2005 [Invited].
  - Gardner, K., B.L. McGlynn, D. Patten, J. Shanley. 2005. Impact of mountain resort development on watershed nitrogen export: the importance of spatial location, Montana American Water Resources Association (AWRA) Annual Meeting, Bozeman, Montana.
  - Gardner, K.K. McGlynn, B.L, D. Patten., R. Lawrence, L. Graumlich, and J. Shanley. 2006. Effects of Mountain Resort Development on Streamwater Nitrogen Export: the Importance of Spatial Location, Gordon Conference on Catchment: Interactions of Hydrology, Biology & Geochemistry Science Biannual Meeting, Waterville, Maine.
  - Gardner, K.K. McGlynn, B.L, D. Patten, and J. Shanley. 2004. Impact of land use change on streamwater quality, Big Sky,

Montana, American Water Resources Association (AWRA) Annual Meeting, Helena, Montana. Second Prize Student Poster.

- Other Publications:
  - Gardner, K.K., Harder, J.I. 2006. Collaboration between Ophir School, Blue Water Task Force Watershed group, and Montana State University research. Montana Watercourse Watershed Tour on Collaborative Education, Big Sky, Montana.
  - Gardner, K., B.L. McGlynn. 2005. Water Quality a Growing Concern in Mountain Watersheds, Big Sky Institute Mountains and Minds Lecture, Big Sky, Montana.
  - Gardner, K.K. 2005. Stream Sleuth: Why is there more nitrogen in the West Fork Watershed? Ophir School Assembly, Big Sky, Montana.
  - Gardner, K.K. 2005. Nutrient Movement in the West Fork Watershed. Montana Watercourse Watershed Tour, Big Sky, Montana.

Report Follows

The Impact of Land Use/Land Cover Change on Nitrogen Export in Mountain Watersheds: the Importance of Spatial Location

Kristin K. Gardner Brian L. McGlynn

Abstract

Southwestern Montana has experienced rapid growth in recent years; 16 counties grew by more than 14% between 1990 -2000; Ravalli and Gallatin counties alone grew 34 and 44 percent, respectively (MSGC, 2004). Human alteration of the patterns of land use/land cover (LULC) on the earth surface is one of the most profound impacts on natural ecosystems. Understanding the consequences of LULC change is a critical issue. At the watershed scale, we expect that not only the amount and type of landscape alteration, but also the spatial location, will dictate the corresponding impacts on streamwater quality. Therefore, we hypothesize that the spatial arrangement of LULC in the landscape is a principal control on both the spatial and temporal patterns of streamwater nitrogen (N). This research develops innovative methods to examine the impact of spatial location of LULC change on streamwater quality by combining spatially distributed field sampling of water quality parameters and digital terrain analysis with a new N export coefficient model. The export coefficient model will be validated by performing isotopic analysis using ^{15}N and ^{18}O of NO_3^- to identify streamwater nitrate sources. The relationships quantified in the export coefficient model and validated by field sampling will 1) help assess watershed N status and the spatial and geographic characteristics that control watershed N export, and 2) provide land managers with a tool to identify areas vulnerable to N export and thus the ability to guide lower impact development. The results of our study will provide insight into the impact of human alteration of natural landscapes on streamwater quality. Although our research focuses on mountain resort development in high elevation settings, our concepts and methodologies will be widely applicable to other landscapes.

Research Objectives

LULC change has been shown to be a significant threat to water resources (Cole et al., 1993; Mayer et al., 2002; Wernick et al., 1998; Biggs et al., 2004; Gardner and Vogel, 2004), and yet the understanding of linkages between land use, water quality, and N export in streams is inadequate to inform land management decisions. Development of Big Sky Mountain Resort in Southwestern Montana has resulted in extensive changes in landscape cover. Initial development occurred in the 1970s and is occurring at an increasingly rapid rate today. Preliminary analysis illustrates a similar upward trend in housing development and streamwater NO_3^- concentration in the West Fork River (Figure 1).

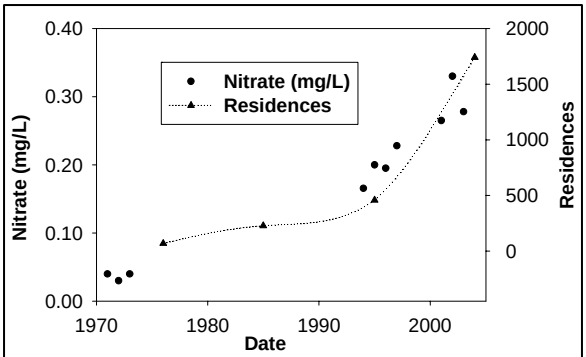

Figure 1: Similar time trends in streamwater nitrate concentration and residential development in the West Fork watershed.

Our analysis approach combines valuable historical data and new data collection in a rapidly developing mountain watershed to assess the characteristics of LULC change governing watershed N export and streamwater quality. Accordingly, we will address the following objectives:

Objective 1: Analyze the current spatial and seasonal variability of N export, land use/land cover (LULC), and watershed characteristics**.**

a. Perform synoptic sampling for water quality (major ions, N species, $\delta^{15}N$ and $\delta^{18}O$ of NO_3^-) in the West Fork and selected tributaries four times throughout the year, to capture major hydrologic events and growing seasons (onset of peak flow, peak flow, baseflow growing season, and baseflow dormant season).
b. Perform weekly streamwater sampling in subwatersheds with varying levels of development (and distribution of LULC), determined from Objective 1a, to ascertain potential differences in the seasonal variability of N export, in developed versus undeveloped watersheds.
c. Determine present LULC and watershed characteristics in the West Fork watershed using a combination of high-resolution remote sensing (QuickBird) and topography data.

Objective 2: Develop and validate a geographically-based nitrogen export model to ascertain and model first-order controls of streamwater NO_3^- concentration and provide a mapping tool for land managers to determine spatial vulnerability in mountainous watersheds.

a. Develop nitrogen export model incorporating results of Objective 1a and b
b. Validate model by performing $^{15}N/^{14}N$, $\delta^{18}O$ isotopic analysis to ascertain sources of streamwater NO_3^-.
c. Apply model spatially to map NO_3^- loading vulnerability to provide tool for land managers to determine spatial patterns of vulnerability in mountainous watersheds.

Study Site

The West Fork River, a tributary of the Gallatin River, drains the Big Sky, Moonlight Basin, Yellowstone Club and Spanish Peaks resort areas and the meadow village located near the outlet. The area is situated in the northern Rocky Mountains of southwestern Montana. The West Fork (212 km^2) is formed by three main tributaries: the South Fork (SF) (121 km^2), the Middle Fork (MF) (48 km^2) and the North Fork (NF) (24 km^2). The watershed (Figure 2) is characterized by well defined steep topography and shallow soils. Elevation in the drainage ranges from ~1800 to 3400 meters, accounting for a great variation in precipitation between the headwaters and mouth. Average annual precipitation exceeds 127 cm at higher altitudes and is less than 50 cm in valley bottoms. Most precipitation falls during the winter and spring months. A hydrograph of the West Fork indicates a general recession throughout the autumn and winter months followed by peak flows during spring snowmelt (Van Voast, 1972).

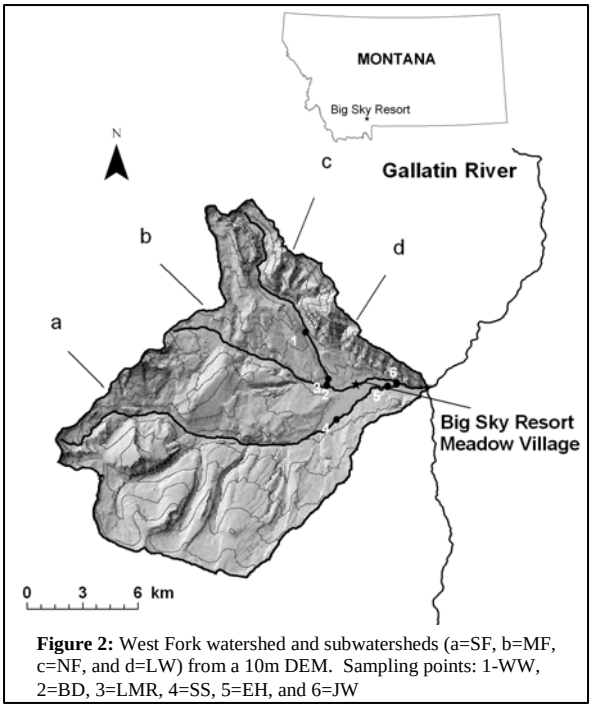

Figure 2: West Fork watershed and subwatersheds (a=SF, b=MF, c=NF, and d=LW) from a 10m DEM. Sampling points: 1-WW, 2=BD, 3=LMR, 4=SS, 5=EH, and 6=JW

Progress to date

Research Objective 1a:

We completed 3 synoptic sampling events in September 2005, February 2006, and June 2006. At each synoptic event, streamwater samples were collected from 54 sites in the West Fork Watershed. Sites were chosen to capture differing land use and watershed characteristics exhibited in the West Fork Watershed (Figure 3). We were unable to collect samples from the southwestern area due to access issues. Samples were collected in 250mL bottles, filtered with a .4um filter and chilled until analysis. We have analyzed a portion of the synoptic samples collected for anions.

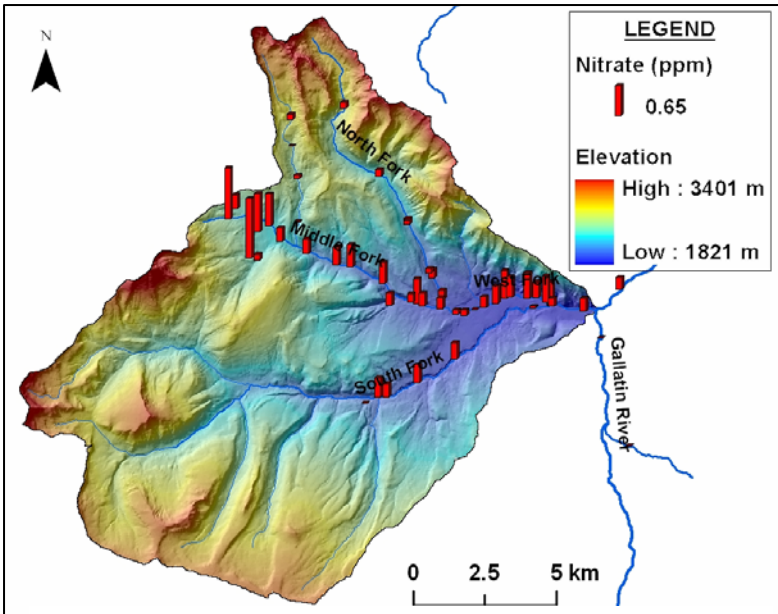

Figure 3: Streamwater nitrate concentrations (ppm) in the West Fork Watershed, September 2005.

Stream flow was measured with a Marsh-McBirney Flo-Mate 2000 portable flow in velocity-area gauging of the stream.

Water samples are being analyzed for major ions with a Metrohm-Peak compact ion chromatograph. Nitrate (NO_3), nitrite (NO_2), chloride (Cl), bromide (Br), phosphate (PO_4), and sulfate (SO_4) are measured on a Metrosep C-2-250 anion column. Sodium (Na), ammonium (NH_4), potassium (K), calcium (Ca), and magnesium (Mg) will be measured on a Metrosep C-2-250 cation column.

Research Objective 1b:

Water samples have been collected on a weekly basis since November 2004 at 7 sites within the West Fork Watershed and 2 sites on the Gallatin River. Sites were chosen to capture differing upslope land use and watershed characteristics and also to continue collection at sites with a historical record. Flow, EC, and temperature were measured at each spot. Samples were collected in 250mL bottles, filtered with a .4um filter and chilled until analysis. We have analyzed a portion of the synoptic samples collected for anions.

Research Objective 1b:

- The *QuickBird imagery data* has been collected and is now being orthorectified by Digital Globe.
- The *ALSM topography data* has been collected, processed and delivered to us, however it has not been analyzed yet.

Research Objective 2a: no progress to date

Research Objective 2b: Twenty of the streamwater samples from the February 2006 synoptic sampling event have been sent to Woods Hole Oceanographic Marine Microbial Biogeochemistry Lab for $^{15}N/^{14}N$, $\delta^{18}O$ isotopic analysis to ascertain sources of streamwater NO_3^-. The results of the isotopic analysis will aid in validating the nitrogen export model.

Research Objective 2c: no progress to date

Expected Results

Our research will improve upon existing methods to quantify the impact of land use/land cover (LULC) change on streamwater quality, by applying an innovative method incorporating the spatial patterns and topographical relationships of LULC. Currently, no framework exists for integrating landscape analysis with LULC to provide context for streamwater quality. Our research will contribute an innovative methodology to model critical N export areas by incorporating topography, topology and LULC which fill critical gaps in characterizing landscape nutrient export to surface water.

This study will set the stage to conduct further research by supplying the necessary information to select smaller scale research sites for more in depth hydrological, biogeochemical and ecological process study examining the impacts of LULC change. Thus, our project will initiate the foundation and infrastructure for a long-term, community-driven, integrated research site equipped to monitor the impact of recreational development on mountain ecosystems. We have received several sources of funding for this project since we received the USGS 104(b) seed grant (see tracking below) and we are currently preparing another proposal for the National Science Foundation's Research Initiation Grants and Career Advancement Awards to Broaden Participation in the Biological Sciences program.

Thus far, our research has been presented numerous times at professional conferences, as well as the Big Sky community (see tracking below). As part of our research, we have partnered with the Blue Water Task Force (BWTF), a local watershed group; the Greater Gallatin Watershed Council (GGWC), an umbrella group coordinating water-related projects, the Big Sky Institute for Science and Natural History, and the Ophir School, a local K-8 school in the West Fork Watershed. Public involvement in the synoptic sampling has been incorporated by field training in collaboration with the BWTF. Teacher training and linkages between research and K-12 education has been made through collaboration with the BSI for Science and Natural History and local watershed groups. Gardner is currently a Big Sky Institute NSF GK-12 Fellow and has focused on linking this research to Ophir School. Multiple public seminars and field trips focused on landuse change – water quality impacts have also been conducted by our research group.

Expected Timeline

Method	Timeline
Land Use/Land Cover Mapping	September-May (2006-7)
Synoptic Sampling	August (2005), February, May (2006)
Fine Resolution Sampling	Continuous sampling
Modelling and Results	May 2008

References

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Wernick B.G., Cook K.E., Schreie,r H. 1998. Land use and streamwater nitrate-N dynamics in an urban-rural fringe watershed. *Journal of the American Water Resources Association*, 34 (3): 639-650.

Tracking

1. Conference Presentations:

McGlynn, B.L. and K. Gardner. 2006. *Landuse change impacts on water quality: The importance of spatial location.* Swedish Institute of Hydrology Meeting, Stockholm, Sweden. Invited keynote speaker.

McGlynn, B.L., J. Seibert, R. Gresswell, and D. Bateman. 2006. *Landscape analysis of stream-upland connections: Implications for runoff generation, biogeochemistry, and in-stream habitat*. North American Benthological Society Annual Meeting, Anchorage, Alaska.

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McGlynn. B.L. and J. Seibert. 2005. Hewlett's legacy: *Remaining challenges and possible ways forward*. American Geophysical Union Fall Meeting. Fall, 2005 [Invited].

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2. Community Presentations

Gardner, K.K., Harder, J.I. 2006. *Collaboration between Ophir School, Blue Water Task Force Watershed group, and Montana State University research*. Montana Watercourse Watershed Tour on Collaborative Education, Big Sky, Montana.

Gardner, K., B.L. McGlynn. 2005. *Water Quality a Growing Concern in Mountain Watersheds*, Big Sky Institute Mountains and Minds Lecture, Big Sky, Montana.

Gardner, K.K. 2005. *Stream Sleuth: Why is there more nitrogen in the West Fork Watershed?* Ophir School Assembly, Big Sky, Montana.

Gardner, K.K. 2005. *Nutrient Movement in the West Fork Watershed.* Montana Watercourse Watershed Tour, Big Sky, Montana.

3. Student Support:

Kristin Gardner, PhD
Kristy Segal, Undergraduate

4. Notable Achievement and Awards:

2006-2007 Department of Environmental Quality, Subcontract for EPA 319 Funds for the Upper Gallatin Watershed Nutrient Assessment, $ 66,000.

2005-2006 Department of Environmental Quality, Subcontract for EPA 319 Funds for the Upper Gallatin Watershed Nutrient Assessment, $ 54,000.

2005-2006 US Environmental Protection Agency STAR: *Land Use/Land Cover Change Governing Nitrogen Thresholds and Transport in Mountain Watersheds*, $293,397.

2005 National Science Foundation Geography and Hydrology Program: *Effect of mountain resort development on streamwater nitrogen export: the importance of spatial location*, $33,836.

NSF Graduate Teaching Fellowship in K-12 Education, Kristin Gardner, PhD candidate.

Science to Achieve Results (STAR) fellowship, Kristin Gardner, PhD candidate.